

REPORT DOCUMENTATION PAGE

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| 6. AUTHORS Dinesh Manocha, Ming C. Lin | | 5d. PROJECT NUMBER | | |
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| | | 5f. WORK UNIT NUMBER | | |
| 7. PERFORMING ORGANIZATION NAMES AND ADDRESSES University of North Carolina - Chapel Hill Office of Sponsored Research 104 Airport Drive, Suite 2200, CB 1350 Chapel Hill, NC 27599 -1350 | | 8. PERFORMING ORGANIZATION REPORT NUMBER | | |
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| 14. ABSTRACT See attachment | | | | |
| 15. SUBJECT TERMS massive models, interactive simulation and visualization, Computer generated forces | | | | |
| 16. SECURITY CLASSIFICATION OF: a. REPORT UU | | 17. LIMITATION OF ABSTRACT b. ABSTRACT U | 15. NUMBER OF PAGES c. THIS PAGE U | 19a. NAME OF RESPONSIBLE PERSON Dinesh Manocha |
| | | | | 19b. TELEPHONE NUMBER 919-962-1749 |

Report Title

Final Report for ARO Grant:

" Handling Massive Models: Representation, Real-Time Display and Interaction"

ABSTRACT

See attachment

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 19.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 11.00

(c) Presentations

Number of Presentations: 6.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 8

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 33

(d) Manuscripts

Number of Manuscripts: 0.00

Number of Inventions:

Graduate Students

| <u>NAME</u> | <u>PERCENT SUPPORTED</u> |
|------------------------|--------------------------|
| See Attachment | |
| FTE Equivalent: | |
| Total Number: | 1 |

Names of Post Doctorates

| | |
|-------------|--------------------------|
| <u>NAME</u> | <u>PERCENT SUPPORTED</u> |
|-------------|--------------------------|

FTE Equivalent:

Total Number:

Names of Faculty Supported

| | | |
|------------------------|--------------------------|-------------------------|
| <u>NAME</u> | <u>PERCENT SUPPORTED</u> | National Academy Member |
| Ming C Lin | 0.10 | No |
| Dinesh Manocha | 0.10 | No |
| FTE Equivalent: | 0.20 | |
| Total Number: | 2 | |

Names of Under Graduate students supported

| | |
|-------------|--------------------------|
| <u>NAME</u> | <u>PERCENT SUPPORTED</u> |
|-------------|--------------------------|

FTE Equivalent:

Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 1.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 1.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

| |
|-------------|
| <u>NAME</u> |
|-------------|

Total Number:

Names of personnel receiving PHDs

| |
|-------------|
| <u>NAME</u> |
|-------------|

See Attachment

Total Number:

1

Names of other research staff

NAME

PERCENT SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

PROJECT TITLE: Handling Massive Models: Representation, Real-Time Display and Interaction

INTERIM PROJECT REPORT

Contract Number: DAAD19-02-1-0390

Name(s) of Principal Investigator(s): Dinesh Manocha
Ming C. Lin

Name of Organization: University of N. Carolina at Chapel Hill

Address, including ZIP Code: Department of Computer Science, Chapel Hill,

NC 27599-3175

Telephone Number: (919) 962-1749

FAX Number: (919) 962-1799

Email Address: dm@cs.unc.edu

WWW Homepage: <http://www.cs.unc.edu/~dm>

1. Technical Objectives and Motivation

We propose to address some fundamental research issues in handling and visualizing massive models, composed of millions of primitives. These include efficient representations, interactive display and real-time interaction. These models arise in many applications, including computer-aided design, simulation-based design, lethality and vulnerability analysis, medical simulation, surgical training and scientific visualization. Our goal is to develop efficient algorithms and systems, and demonstrate their performance on massive environments composed of millions of primitives. The set of research problems that we worked on included:

1. Hierarchical and multiresolution representations of models for fast display.
2. Interactive display of large polygonal, sculptured, sampled or solid models on current graphics systems.
3. Interactive proximity queries and collision response between rigid and deformable models in a large, complex environment.
4. Real-time interaction with the virtual world.

2. Approach

We used a number of techniques from algebraic geometry, approximation theory, computational geometry, numerical analysis, computer-aided geometric

design and computer graphics to investigate the underlying mathematical concepts and to develop more efficient and robust geometric algorithms. This included algorithms and systems for representing massive models, rendering them at interactive rates, collision detection and interaction.

3. Significant Accomplishments

The PI and his student developed novel algorithms for boundary computation, model simplification, fast display and interference detection, model representation, ray tracing, physical simulation and multiresolution techniques

The resulting algorithms and systems have been applied to a number of applications and the technology has been transferred to a number of research and DOD labs as well as commercial vendors.

4. Cooperation with and Technology Transfer to Army Laboratories and Other Organizations

A: Army Research Labs, Aberdeen, MD: The PI and his graduate students are integrating our solid modeler, BOOLE, with the BRL-CAD solid modeling system developed by researchers at Army Research Labs, Aberdeen. BRL-CAD is primarily used for vulnerability analysis at ARL and it has more than \$1600\$ users worldwide. BOOLE has been used for performing boolean operations on curved surfaces.

B: Collision Detection System: More than 15000 users all over the world have copied the source code of the I-COLLIDE, V-COLLIDE, SWIFT, SWIFT++, DeformCD and PQP collision detection systems. Some of the prominent users are at Sandia National Labs, Lockheed Martin, Ford Motor Company, Division, Engineering Animation, Army Research Labs, Evans and Sutherland, etc. More than 40 commercial organizations have licensed these technologies.

C: We have been collaborating closely with RDECOM STTC at Orlando, FL on incorporating our GPU-based technologies and new algorithms for dynamic terrains into OneSAF and Computer-Generated Force Systems. Earlier some of our algorithms for LOS and route planning were incorporated into OOS. We also worked with ARA, SAIC and Future Combat Systems (FCS) to incorporate our technologies for dynamic datasets and dynamic terrains into OneSAF. We have demonstrated these technologies at PEO-STRI, I/ITSEC 2007 and Capitol Hill demonstration in February 2007.

5. Publications in Refereed Journals and Conference Proceedings

V. Kwatra, D. Adalsteinsson, T. Kim, N. Kwatra, M. Carlson, and M. Lin, ""Texturing Fluids""", IEEE Trans. on Visualization and Computer Graphics, p. , vol. , (2007). Accepted,

T. Kim and M. Lin, ""Stable Advection-Reaction-Diffusion with Arbitrary Anisotropy"", Journal of Computer Animation and Virtual World, Special Issue, p. , vol. , (2007). Published,

T. Kim and M. Lin, "Fast Animation of Lightning Using Adaptive Meshes", IEEE Trans on Visualization and Computer Graphics, p. 390, vol. 13, (2007). Published,

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J. Wendt, W. Baxter, I. Oguz, and M. Lin, ""Finite-Volume Flow Simulations in Arbitrary Domains"", Graphical Models, p. 19, vol. 69, (2007). Published,

M. A. Otaduy and M. C. Lin, ""A Haptic Rendering Pipeline for Stable and Responsive Six-Degree-of-Freedom Manipulation", IEEE Trans. on Robotics, p. 751f, vol. 22, (2006). Published,

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N. Govindaraju, M. Lin, and D. Manocha, ""Efficient Collision Culling among Deformable Objects using Graphics Processors"", Presence, p. 62, vol. 15, (2006). Published,

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Avneesh Sud, Liangjun Zhang, Mark Foskey, Dinesh Manocha, "Homotopy Preserving Approximate Voronoi Diagram of 3D", Computer Graphics Forum, p. , vol. , (2007). Published,

Sung-Eui Yoon, Dinesh Manocha, "Cache-Efficient Layouts of Bounding Volume Hierarchies", Proc. of Eurographics Forum, p. , vol. , (2006). Published,

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Gokul Varadhan, Dinesh Manocha, "Star-shaped Roadmaps - A Deterministic Sampling Approach for Complete Motion Planning", International Journal of Robotics Research, p. , vol. , (2007). Published,

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Jur van den Berg, Ming C. Lin, Dinesh Manocha, "Reciprocal Velocity Obstacles for Real-Time Multi-Agent Navigation", IEEE International Conference on Robotics and Automation (ICRA), p. , vol. , (2008). Published,

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Rahul Narain, Vivek Kwatra, Huai-Ping Lee, Theodore Kim, Mark Carlson, Ming C. Lin, "Feature-guided Dynamic Texture Synthesis on Continuous Flows", Eurographics Symposium on Rendering, p. , vol. , (2007). Published,

Nico Galoppo, Serhat Tekin, Miguel A. Otaduy, Markus Gross, Ming C. Lin, "Haptic Rendering of High-Resolution Deformable Objects", 12th International Conference on Human-Computer Interaction, Beijing, China, p. , vol. , (2007) . Published,

Christian Lauterbach, Anish Chandak, Dinesh Manocha, "Interactive Sound Propagation in Dynamic Scenes Using Frustum Tracing", IEEE Visualization, p. , vol. , (2007) . Published,

Russell Gayle, Kristopher Klingler, Patrick G. Xavier, "Lazy Reconfiguration Forests (LRF): An Approach for Motion Planning with Multiple Tasks in Dynamic Environments", International Conference on Robotics and Automation (ICRA), p. , vol. , (2007) . Published,

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Russell Gayle, Avneesh Sud, Ming C. Lin, Dinesh Manocha, "Reactive Deforming Roadmaps: Motion Planning of Multiple Robots in Dynamic Environments", IEEE/RSJ International Conference On Intelligent Robots and Systems (IROS), p. , vol. , (2007) . Published,

David Kasik, Dinesh Manocha, Philipp Slusallek, "Real-Time Interaction with Complex Models", IEEE Computer Graphics and Applications, p. , vol. , (2007) . Published,

Avneesh Sud, Russell Gayle, Stephen Guy, Erik Andersen, Ming C. Lin, Dinesh Manocha, "Real-time Navigation of Independent Agents Using Adaptive Roadmaps", Proc. ACM Symposium VRST, p. , vol. , (2007) . Published,

Avneesh Sud, Erik Andersen, Sean Curtis, Ming C. Lin, Dinesh Manocha, "Real-time Path Planning for Virtual Agents in Dynamic Environments", IEEE Virtual Reality, p. , vol. , (2007) . Published,

Nikunj Raghuvanshi, Christian Lauterbach, Anish Chandak, Dinesh Manocha, Ming C. Lin, "Real-time sound synthesis and propagation for games", Communications of ACM. Special Issue on Games, p. , vol. , (2007) . Published,

Nico Galoppo, Miguel A. Otaduy, Serhat Tekin, Markus Gross, Ming C. Lin, "Soft Articulated Characters with Fast Contact Handling", ACM SIGGRAPH/Eurographics Conference, Vienna, p. , vol. , (2007) . Published,

Avneesh Sud, Naga K. Govindaraju, Russell Gayle, Erik Andersen, Dinesh Manocha, "Surface Distance Maps", Graphics Interface, p. , vol. , (2007). Published,

Miguel A. Otaduy and Ming C. Lin, ""High-Fidelity Haptic Rendering"", (2006). Book, Published
Bibliography: Morgan-Claypool

Nico Galoppo, M. Otaduy, S. Tekin, M. Gross, and M. Lin, "Fast Contact Dynamics for Deformable Articulated Characters", (2007). Proc. of Eurographics, Accepted

R. Gayle, A. Sud, M. Lin, and D. Manocha, "Reactive Deformation Roadmaps: Motion Planning of Multiple Robots in Dynamic Environments", (2007). Proc. of IROS 2007, Published

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Collection: Proc. of Eurographics Workshop on Natural Phenomena

R. Narain, V. Kwatra, T. Kim, H. Lee, M. Carlson, and M. Lin, "Feature-Guided Dynamic Texture Synthesis on Continuous Flows", (2007). ,
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N. Galoppo, M. Otaduy, S. Tekin, M. Gross, and M. Lin, "Haptic Rendering Using Dynamic Deformation Textures", (2007). , Published
Bibliography: 10 pages

I. Kabul, R. Gayle, and M. Lin, "Cable Route Planning in Complex Environments Using Constrained Sampling", (2007). , Published
Collection: Proc. ACM Symposium on Solid and Physical Modeling and Applications

R. Gayle, M. Lin, and D. Manocha, "Efficient Motion Planning of Highly Articulated Chains using Physics-based Sampling", (2007). ,
Collection: Proc. of IEEE International Conference on Robotics and Automotion

A. Sud, E. Andersen, S. Curtis, M. Lin, and D. Manocha, "Real-time Path Planning for Virtual Agents in Dynamic Environments", (2007).
Collection: Proc. of IEEE Virtual Reality 2007

T. Kim, D. Adalsteinsson and M. Lin, "Modeling Ice Dynamics As a Thin-Film Stefan Problem", (2006). Cover Image Article, Published
Collection: Proc. of ACM SIGGRAPH/Eurographics Symposium on Computer Animation

N. Galoppo, M. Otaduy, P. Mecklenburg, M. Gross, and M. Lin, "Fast Simulation of Deformable Models in Contact Using Dynamic Deformation Textures", (2006). , Published
Collection: Proc. of ACM SIGGRAPH/Eurographics Symposium on Computer Animation

R. Gayle, M. Lin, and D. Manocha, "Adaptive Dynamics with Efficient Contact Handling for Articulated Robots", (2006). , Published Collection: Proc. of Robotics: Science and System

N. Govindaraju, I. Kabul, M. C. Lin, and D. Manocha, "Fast Continuous Collision Detection among Deformable Models using Graphics Processor", (2006). , Published Collection: Proc. of Eurographics Symposium on Virtual Environments

N. Raghuvanshi and M. Lin, "Interactive Sound Synthesis for Large Scale Environments", (2006). Cover Image Article, Published Collection: Proc. of ACM Symposium on Interactive 3D Graphics and Games

K. Ward, N. Galoppo, and M. Lin, "A Simulation-based VR System for Interactive Hairstyling", (2006). (Short Paper), Published Collection: Proc. of IEEE Virtual Reality 2006

J. Schonher, M. Falvo, S. Lord, R. Taylor II, and M. Lin, "Interactive Simulation of Fibrin Fibers in Virtual Environments", (2006). , Published Collection: Proc. of IEEE Virtual Reality 2006

M.C. Lin, "Collision and Proximity Queries", (2007). Handbook/Encyclopedia, Accepted Editor(s): Benjamin Walsh Collection: Encyclopedia of Computer Science and Engineering

6. HONORS and AWARDS

Best Paper Award, ACM Solid and Physical Modeling (2003)

Best Paper Award, IEEE VR (2005)

ACM SIGMOD Sorting Benchmark Award (2006)

Phi Delta Theta/Mason Distinguished Professorship awarded to Dinesh Manocha (2006)

Beverly Long Distinguished Professorship awarded to Ming C. Lin (2007)

7. Papers or reports in non-refereed publications

8. Books or book chapters published

See the publications above.

9. Patent/Inventions filed or granted

10. Number of graduate and undergraduate students supported by gender and by minority group

See the list below

11. Number of MS and Ph.D. degrees awarded to students working through the grant and their current employment status and employers

Bill Baxter, Ph.D. 2004 (male)
Miguel Otaduy, Ph.D. 2004 (male)
Kelly Ward, Ph.D. 2005 (female)
Naga Govindaraju, Ph.D. 2004 (male)
Gokul Varadhan, Ph.D. 2005 (male)
Ted Kim, Ph.D., 2006 (male)
Avneesh Sud, Ph.D. 2006 (male)
Brandon Lloyd, Ph.D. 2007 (male)